Modeling of Compressive Strength of Concrete using Gaussian Membership Function

M. Deepak, M. Balamurali, P. Vinoth, J. Jeeva Bharathi, K. Kapilaravindh

Abstract*: This paper presents an application of fuzzy logic to forecast the compressive strength of concrete. The fuzzy model examines 7 different input parameters that comprises: Cement, Coarse aggregate(CA), Super plasticizer(SP), Fine Aggregate(FA), Slag, Fly ash, Water(W), and 28 days compressive strength is taken as the output parameter. By using Gaussian membership function, the fuzzy logic technique is used for developing models. For assessing the results of FL model with experimental results, root mean square error, mean absolute error and correlation coefficient are used. The results showed that FL can be a better modeling tool and an another technique for predicting the concrete's compressive strength.

Keywords: Fuzzy Logic, Gaussian membership function, Compressive strength, Concrete.

I. INTRODUCTION

This Concrete is a material which consists of binder and aggregate particles combined together. [1] The strength of concrete grows as the days getting older in usual circumstances. It takes time to combine the aggregates and solidify the paste which is caused by reactions by cement and concrete. Initially reactions takes place rapidly after that gradually over a period of time [2]. Innovation come on partial substitution of cement with waste by-products like fly ash or ground granulated blast furnace slag (GGBFS) have growing, to reduce the disposal of waste by-products [4]. It is well acknowledged that pozzolana like, silica fume, fly ash, and GGBFS are industrial derived products that present excessive discrepancies of properties, which can occasionally compromise their use [5]. These pozzolanic materials are used as admixtures in cement and concrete production to minimize the cement content. [6]. Fly ash up to 60% can be used, if the early strength is not an crucial fact. Since, at early ages fly ash usually results in undesirable effects on the concrete strength [7,8]. For dipping the cracking and heat of hydration at primary ages in concrete, fly ash obtained from coal-fired power plants can be utilized. The compressive strength for long-term and longevity can be achieved with concrete in concrete structures containing fly

ash [4]. The concrete containing fly ashes are prepared at lesser of water to binder ratios to obtain enhanced strength and durability performance.

Generally the compressive strength test are performed at 7 as well as 28 days with the date of casting. Normally after 28 days testing are done and can be also done at different ages according to the necessity. [9-12].

Nowadays many researchers use widespread data exploration techniques such as artificial neural network, fuzzy logic, for all varieties of engineering applications. The primary driving force for presenting fuzzy concepts is to express the uncertain concepts. It requires a straightforward method based on engineering expertise to manage the complicated mathematical models. It is simple and comfortable to work with fuzzy logic for examining the impacts of individual variable on the proportion of mix in numerical experiments. [9-12]

II. FUZZY LOGIC

Zadeh established the idea of ''fuzzy Logic'' [13]. FL idea offers a method of handling with problems where the basis of fuzziness is the lack of definite described conditions [10, 14]. Fuzzy logic offers an efficient calculus to interact with many of these data Ideally. Utilizing linguistic labels simulated simply by membership functions, Fuzzy approach performs numerical computation [15].

The important thing in fuzzy logic is the grant of limited properties of various kind of stuffs with the purpose of diverse subsets of the widespread set as an alternative of fitting to a only one set totally. Limited properties to a set can be defined mathematically with a membership function that adopts standards that have among 0 and 1, angular fuzzy sets, Intuition, rank purchasing, inference, neural networks and inductive thinking are the various methods to assign regular membership values. For example, figure 1 depicts a distinctive membership function with class sizes small, medium ,and large proposed in a universal set, U. The figure shows the values lying below 2 are considered "small", those ranging from 4 to 6 are considered "medium" and those values above 8 are considered absolutely "large". But, in-between values for example 2.3 are the part of the subsets to some extent. According to fuzzy concepts, 2.3 has a membership function value of 0.0 in "large", however 0.9 in "small" and 0.1 in "medium" subsets. [10, 14, 16, 25]

Revised Manuscript Received on December 30, 2019.
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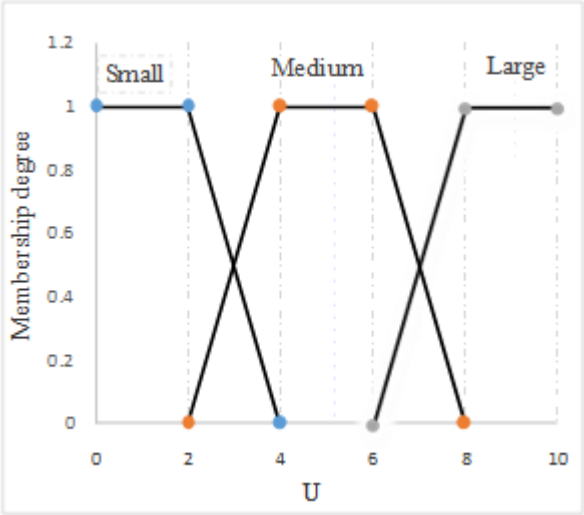

Figure 1: A Typical Membership Function

A common fuzzy inference system (FIS) has fundamentally four parts:

(1) Fuzzy rule base

(2) Fuzzification

(3) Defuzzification

(4) Fuzzy output engine

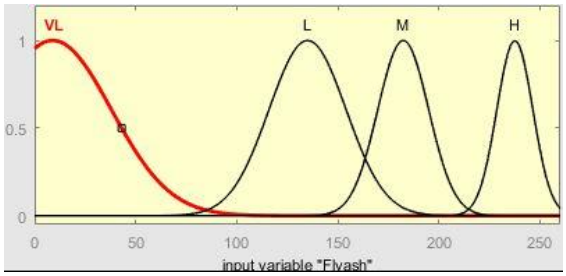

Figure 2: Diagrammatic Representation of Fuzzy System

Figure 2 displays the diagrammatic representation of fuzzy system. Fuzzification means all the input values are transformed to degrees of membership by searching more number of membership functions. all feasible relations that is the relation between the input and output are available in Fuzzy rule base. These rules are defined in the IF-THEN format. Mamdani type, and Sugeno type are the mainly two type of rule base, every fuzzy rules in the fuzzy rule base acquires knowledge on in what way to change a set of inputs to the equivalent outputs are taken into account by Fuzzy inference engine, product (prod) and minimization (min) are the two types of inference operators. From the fuzzy inference engine, defuzzification transforms the fuzzy output into a number. centroid, rightmost maximum, mean of maxima, leftmost maximum, bisector of area are the numerous defuzzification methods. Parameter prediction and Structure identification are the two stages in Fuzzy modeling involving in identification task. choosing the related input variables, picking a particular kind of FIS, defining their antecedents and consequents, and the number of fuzzy rules, and evaluating the number of membership functions and its type are the issues included in structure identification. Ascertainment of targeted values response to apparent input values of incorporated model, are included in parameter forecasting**.** For this purpose 35 data results have been used in the fuzzy model and they were displayed in table I. Training the model means to give the data so that it will learn and provides the output that is strength.

In the current study, the mamdani fuzzy rule type is used to create the fuzzy model and the min method was chosen due to its more accurate results. For defuzzification of the fuzzy output, centroid method was implemented. Membership functions would be the essential part of the fuzzy logic. Based on ranges and variability of input and output data the membership functions were equipped accordingly. Gaussian membership function was chosen. The Gaussian membership functions for various variables are displayed in Figure 3 (a–h). The ranges of the variables were given is table II and the fuzzy rule sets in table III.

The seven major variables used for FL are water, fine aggregate, SP ,Cement ,Coarse aggregate, Slag .[24].

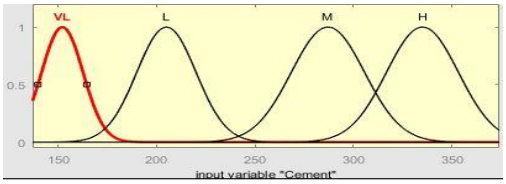

Figure 3a: Membership Function of Cement

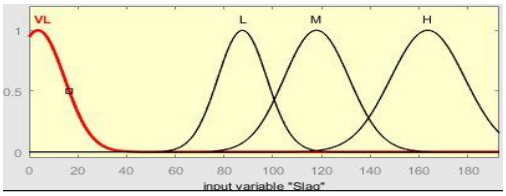

Figure3b: Membership Function of Slag

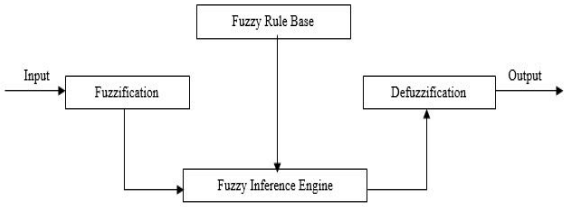

Figure3c: Membership Function of Fly Ash

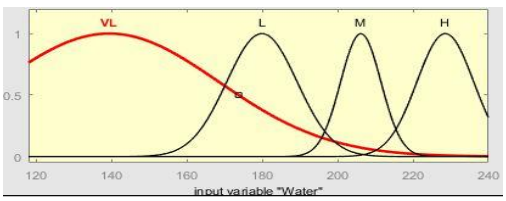

Figure 3d: Membership Function of Water

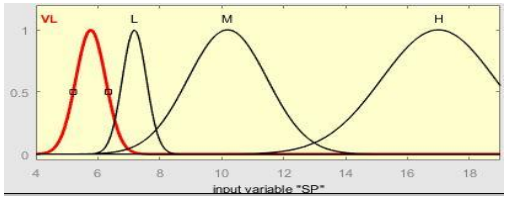

Figure 3e:Membership Function of Super Plasticizer

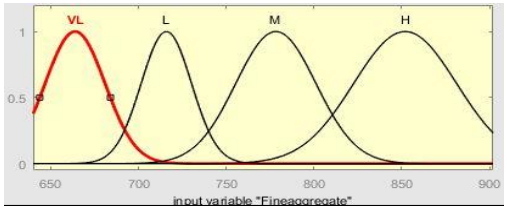

Figure 3g: Membership Function of Fine Aggregate

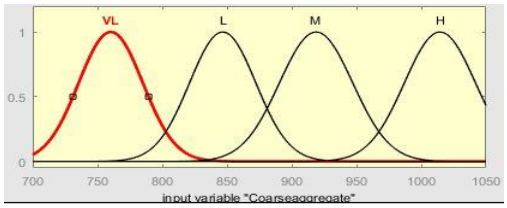

Figure 3f: Membership Function of Coarse Aggregate

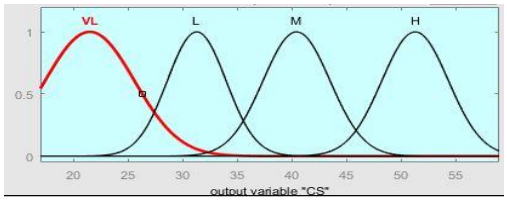

Figure 3h: Membership Function of Compressive Strength

Table- I: Particulars of data used in modeling

Cement	Slag	FA	Water	SP	CA	FA	Compressive Strength at 28 days	
							Measured strength	Predicted strength
140	150	0	182	12	1023	729	18.26	23.3
149	112	144	220	10	923	658	26.82	29.8
145	105	0	205	6	859	797	27.62	27.6
146	106	137	209	6	875	765	27.89	32.9
142	112	0	220	10	794	789	28.16	28.6
147	107	0	210	10	881	745	28.29	27.3
150.3	97	0	219	9	932	685	29.23	28.6
143.3	124	0	205	11	846	758	29.63	25.4
143	116	0	196	10	818	813	29.77	28.2
150.4	100	0	196	10	959	705	29.77	27.3
152	0.6	209.5	118.8	4.6	996.1	789.2	30.43	30.7
145	104	0	231	9	857	725	30.43	33.4
154	1.4	198.1	174.9	4.4	1049.9	780.5	30.83	33.4
148	110	0	189	10	904	765	31.5	26.9
166	126	0	210	6	861	737	31.77	26.5
159	136	0	225	11	770	747	32.04	30.3
162	141	181	234	11	797	683	33.51	37.5

158	0	227	240	6	750	853	36.59	39.9
291	106	136	206	11	750	766	41.01	45.9
296	149	191	180	12	843	746	41.14	45.8
299	107	137	201	6	878	655	41.27	46.8
295.3	148	191	179	16	840	743	41.81	45.9
295	148	190	179	19	838	741	42.08	44.5
295	111	142	217	10	783	686	42.08	45.9
305	94	121	188	9	904	696	43.01	44.9
321	99	127	184	13	810	790	43.54	43.3
320	0	178	230	6	785	721	43.95	46.8
326	90	116	180	9	870	768	44.08	44.8
320	0	239.9	236.2	8.3	780.3	722.9	44.08	46.4
318	0.2	239.8	236.4	8.3	780.1	715.3	44.48	46.4
348.7	40.9	239.9	194	7.5	908.9	651.8	49.19	49.6
349	0	143	168	10	914	804	49.3	50.7
354	88	239.6	175.3	7.6	938.9	646	50.5	51.3
342	0	167	174	6	884	792	52.65	49.8
336	0	187	191	7	824	757	52.65	50.6

Table II: Range of variables in database

Variables	Parameters	Abbreviation	Range of Database	
			Minimum	Maximum
Input	Cement (kg/m^3)	C	137	374
	Water (kg/m^3)	W	118.8	240
	Fine Aggregate (kg/m^3)	FA	640.6	902
	Coarse Aggregate(kg/m^3)	CA	708	1049.9
	Fly ash(kg/m^3)	FH	0	260
	Super plasticizer(kg/m^3)	SP	4.4	19
	Slag(kg/m^3)	S	0	193
Output	Compressive Strength 28 days(MPa)	CS	17.19	58.53

Table III: The Fuzzy Rule Sets

Rule Number	Cement	Slag	Fly ash	Water	SP	CA	FA	Compressive strength
1	VL	H	VL	L	M	M	M	VL
2	VL	H	VL	L	M	H	L	VL

3	VL	H	VL	L	M	H	M	VL
4	VL	L	L	M	M	L	H	L
5	VL	M	L	M	M	VL	H	L
6	VL	VL	H	M	VL	H	VL	L
7	VL	M	M	M	VL	M	VL	M
8	VL	VL	L	M	M	L	M	M
9	L	M	H	M	L	M	VL	M
10	L	M	M	L	M	M	M	H
11	M	H	H	L	L	M	VL	H
12	M	M	L	M	VL	VL	M	H
13	H	H	H	L	L	M	VL	H
14	M	H	H	L	L	M	VL	H
15	H	VL	L	L	M	M	L	H
16	H	VL	L	L	M	L	M	H
17	H	VL	L	L	VL	L	L	H
18	H	VL	H	M	M	VL	M	H
19	H	VL	H	L	L	M	VL	H

Table IV: Statistical Results for the Fuzzy Logic Model

III. RESULT AND DISCUSSION

The surface diagrams is used to show off the relationship between input or output variables, and the variation can be visualized more clearly by plotting a graph between input and output values The surface diagrams denotes different input and corresponding output parameters is denoted in Figure 4a and 4b. The efficiency of the model is solely depend on counteract between the model and input data. Figure 5 represents the predicted and the actual values of 28 days compressive strength of concrete comprising different percentage as a substitute of cement with fly ash and slag. Table IV shows the results of statistical parameters, like the root mean squared error (RMSE), the correlation coefficient (CC), and the mean absolute error (MAE) which are performed to have a comparison between predicted and actual values. The RMSE will be upward of or equivalent to MAE at all times; The wide discrepancy between them indicates the greater change in the individual errors in the data-set. 0.949837 is the correlation coefficient of the given data set. The value acquired from CC ensures that compressive strength have a positive correlation. Reducing the values of MAE nearer to zero makes the better fuzzy model. For obtaining good fuzzy model RMSE values must be smaller. The predictive effectiveness of the model can be measured by RMSE. [24]

S.No.	Statistical parameters	Values
1	Correlation Coefficient (CC)	0.949837
2	Root Mean Square Error (RMSE)	3.077871
3	Mean Absolute Error (MAE)	1.075429

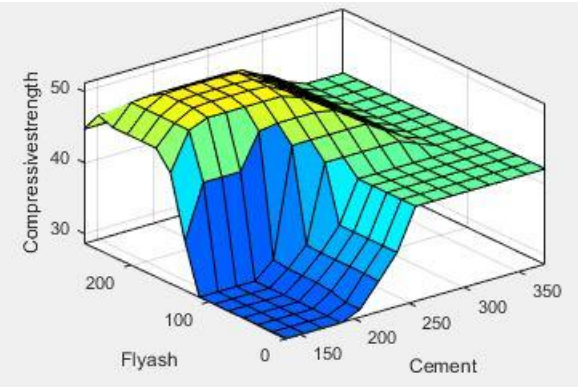

Figure 4a: Surface diagram among Cement, Fly Ash and Compressive Strength

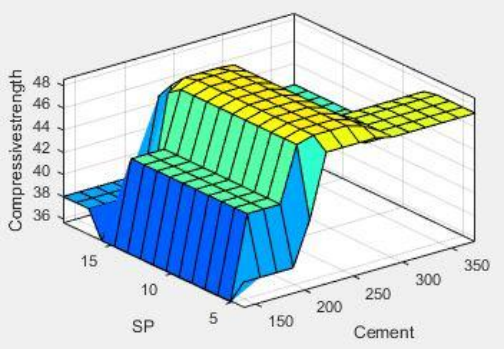

Figure 4b: Surface diagram among Cement, SP and Compressive Strength

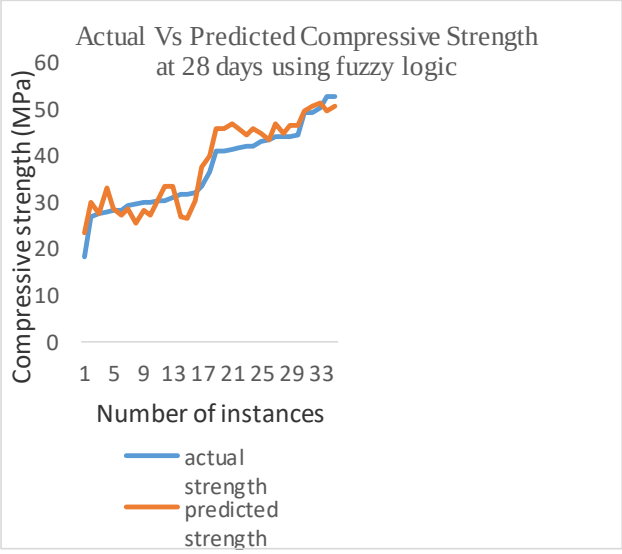

Figure 5: Results of Actual Vs. Predicted Strength at 28 days using Fuzzy Logic

IV.CONCLUSION

In the present work, an FL model was created for predicting 28 days compressive strength of concrete. The experimental outcomes are bit closer to the results acquired from FL models. The Correlation coefficient is 0.949837 which is nearing 1 shows that the correlation among the predicted and actual values. The values of RMSE and MAE were calculated as 1.075429 and 3.077871 respectively. The other methods such as ANN and GA can be used with fuzzy logic to improve its performance. Similarly, using more number of data-sets and supplementary variables, FIS would be even more enhanced. The model's prediction will be more enhanced if it is tried with other membership functions like bell-shaped, sigmoid trapezoidal and more number of data with distinct rule base.

Thus, effective forecast by the model specifies that FL is really a helpful modeling tool intended for engineers and investigators in the domain of concrete and cement. [24]

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